SECRET

ROUTING AND RECORD SHEET

INSTRUCTIONS: Officer designations (see separate sheet) should be used in the "To" column. Under each comment a line should be drawn across sheet and each comment numbered to correspond with the number in the "To" column. Each officer should initial (check mark insufficient) before further routing. This Record and Routing Sheet should be returned to Registry.

25X1A

FROM: [redacted]

ACCESSION NO.

DATE ~~RECEIVED IN S.A.~~ 21 June 1950

		DATE		OFFICER'S INITIALS	COMMENTS
		CEIVED	FORWARDED		
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					
13.					
14.					
15.					

FORM NO. 51-10
SEP 1946

SECRET

(1333)

Approved For Release 2002/01/16 : CIA-RDP83-00415R004400020008-2

CIA
FOREIGN DOCUMENTS DIVISION
[redacted]

25X1A

GENERATION OF DC VOLTAGE FOR A CORONA MEASURING DEVICE

[redacted]

25X1A

21 June 1950

GENERATION OF DC VOLTAGE FOR A CORONA MEASURING DEVICE

Summary: The conditions prevailing in ~~the~~ a large-scale experimental ~~device~~ set-up for power transmission with high-voltage DC ~~show the requirements~~ determine the requirements for voltage and current ~~of~~ for a DC corona measuring device. The voltage should be ~~two-phase~~ double-polarity, ±400 kV against ground, with a direct current of at least 50 mA. The ripple of the DC voltage should be no more than 5%.

For generating ~~of~~ DC voltage with mechanical rectifiers, five different circuits were investigated, using the 500 kV transformers of ~~the~~ a three-phase current measuring device. Of these five circuits, the Greinacher circuit proved to be the most suitable. It supplies ~~DC of~~ 100 mA of DC with a two-phase ripple of ~~2x~~ 2.5%, so that no smoothing is required.

Introduction: The three-phase corona measuring device to be delivered by TRO to MfK is to be expanded by the inclusion of a DC measuring device. Three single-phase transformers with a voltage of 500 kV and an output of 250 kVA are to be used.

The report below investigates the possibilities of generating DC voltage and determines the most suitable circuit by mathematical means.

SECRET

1. Specifications for the DC voltage

1.1) ~~Height~~ Magnitude of the DC voltage: The large-scale experimental set up for power transmission with high-voltage DC and mercury vapor rectifiers has a transmission voltage of 220 kV against ground. The blocking (inverse?) voltage requires the placing in series of two rectifiers. In order to render ~~backfiring~~ arcback harmless, a third rectifier must be connected in series. These difficulties will probably prevent the transmission voltage from being increased during the next few years. It is thus sufficient to carry out corona measurements with a maximum DC voltage of 400 kV against ground.

1.2) DC Power: According to corona measurements performed, the losses with three-phase current in ~~bundled~~ stranded or hollow conductors amount to 150 kW/km or 50 kW/km per phase. For a DC experimental line of 400 m length, a maximum loss current of 50 mA is assumed. At 400 kV, the loss power amounts to 20 kw/400 m or 50 kW/ km per phase.

1.3) Ripple of the DC voltage: The permissible ripple is also contingent on the conditions of power transmission with high-voltage DC. The three-phase bridge circuit, grounded on one side, supplies a DC voltage with six-phase ripple. The effective transformer voltage of the transmission device is $U_T = 98$ kV. The peak value of the DC voltage is

$$U_{g_{max}} = U_T \sqrt{3} \sqrt{2} = 240 \text{ kV.}$$

~~According to the~~ with six-phase ripple, the ignition period is 60°. The DC voltage decreases to the reversing (commutation) point ~~is~~ at

$$U_{g_{min}} = 240 \sin 60^\circ = 208 \text{ kV.}$$

The DC voltage has a mean value of

$$U_g = 2.34\, U_T = 230 \text{ kV.}$$

The ripple of the unsmoothed DC voltage is

$$\frac{(240 - 208)\ 100}{2 \times 230} = 7\%$$

In power transmission, the DC voltage is smoothed by a choke of 5-Henry, in series with the cable capacitance. With the grid control of the rectifiers between 0° and 30°, the ripple will be 1.2 to 3%. ~~In~~ As a first approximation, the AC component will correspond to an effective voltage of

$$U_w = \frac{240 - 208}{2\sqrt{2}} = 11.3 \text{ kV}_{eff}$$

at a freque[illegible]

SECRET

SECRET

At the effective value, the ripple of the unsmoothed DC voltage is

$$\frac{11.3 \times 100}{230} = 4.9\%$$

According to this, it will be desirable to keep the ripple of the DC voltage of the corona measuring device below 5%.

2. Selection of the Circuit for Generation of the DC Voltage

When using tungar tubes for generation of the DC voltage, several tubes would have to be connected in series, because of the high blocking voltage. This cannot be accomplished without potential control. The heat~~ing~~er circuits of the tubes would be expensive, since all tubes would be ~~of~~ at different potential. The required power is also difficult to obtain with tubes. Mechanical rectifiers are thus more suitable as valve arrays.

The TRO has developed a mechanical rectifier in which the blocking voltage ~~is~~ of 500 kV is divided over 11 balls of 50 mm diameter. The contact is accomplished by rotating ~~having~~ 10 identical ~~like~~ balls between the 11 balls on cardboard arms. One rectifier consists of two valve arrays, displaced electrically by 180°.

Only those circuits can be used ~~[illegible]~~ with the mechanical rectifier, which permit the rectifier to be grounded. Otherwise the drive motor would have to be supplied through an isolating ~~[illegible] insulating~~ converter.

A multi~~ple~~-stage multiplication circuit is not required, since the voltage of the testing transformers, $U_T = 500\ kV_{eff}$, is sufficiently high, and since the blocking ability of the mechanical rectifier is adequate. For voltage regulation, a multiplication circuit would be unfavorable. The testing transformers are equipped with step ~~stage~~ regulators. In the case of voltage multiplication, the great control discontinuities in the DC voltage would require the addition of continuous ~~adding of constant~~ control devices.

Because of the transformer utilization factor and the line load, only those circuits can be considered which use ~~utilize~~ both half-waves of the transformer voltage. The center-tap circuit supplies a DC voltage which is too low. Full utilization of the transformer voltage can be accomplished only with bridge circuits. These circuits, however, require four or six valve arrays, while the ordinary doubling circuits require only two valve arrays. The following circuits are thus to be investigated:

~~Three-phase bridge circuit~~

~~Single-phase bridge circuit~~

~~Villard circuit~~

SECRET

Three-phase bridge circuit

Single-phase bridge circuit

Villard circuit

Greinacher circuit

3. The Villard circuit with ball rectifier

3.1) Voltages

The Villard circuit doubles the transformer voltage (cf. Fig. 1). One half-wave of the transformer voltage (Fig. 2) loads condenser C_L through valve V_1. The ~~following~~ other ~~[illegible]~~ half-wave brings the DC condenser C_g to the sum of the voltages of the load condenser C_L and the transformer, through valve V_2.

Peak voltage of the DC :

$$U_g = 2\sqrt{2}\ U_{T_{eff}} = 500 \text{ kV}$$

$$U_T = 500/(2\sqrt{2}) = 250 \text{ kV}_{max}$$

As shown in Fig.2, each valve array must be able to withstand ~~xxxx~~ a blocking voltage double the peak value of the transformer, i.e. 500 kV.

The testing transformers have ~~voltage~~ step control with intervals of ~~with a control discontinuity of~~ 10 kV_{eff}. The control discontinuity in the DC voltage is thus

$$U_r = 2\sqrt{2} \times 10 = 28.3 \text{ kV.}$$

The ripple of the DC voltage is single-phase (Fig.2).

The grounding of one side of the transformer and rectifier ~~is~~ gives favorable results. As the drawing of the potentials (Fig.2) shows, the DC condenser C_g is loaded only once during each period, so that a large condenser is required. A disadvantage of this circuit lies in the fact that the load condenser must be insulated against ground ~~for~~ at the phase potential of the transformer, phase.

3.2) Dimensions of the transformers

The peak value of the DC voltage, 500 kV_{eff}, ~~lies on~~ builds up across the DC condenser C_g. The load condenser C_L must be dimensioned for the peak value of the transformer voltage of 250 kV_{max} and must be insulated against ground for 250 kV_{max}.

The highest corona current at a DC voltage of 500 kV is to be 50 mA (see above). With a three-phase bridge circuit, the voltage fluctuates by 30 kV. A fluctuation of 30 kV per period is admissible also for the corona device. The capacitance of the condensers is to be calculated accordingly.

Discharge of the DC condenser in one period:

$Q_e = 0.05\ A\ .0.02\ s = 0.001\ As$

$U_{max} = 500\ kV$

$U_{min} = 470\ kV$

1) $Q = C\ U_{max}$

2) $Q' = C\ U_{min}$

3) $Q_e = Q - Q' = 0.001\ As$

1.) $C = Q/U_{max}$ 2.) $C = Q'/U_{min}$

1,2) $U_{min}/U_{max} = Q'/Q = 470/500$

$Q' = Q\ (470/500)$

3.) $Q - Q\ (470/500) = 0.001$

$(30/500)\ Q = 0.001$

$Q = 0.0167$ Coulomb

1.) $C = Q/(U_{max}) = 0.0167\ /\ 500000$

$C = 0.033$ mfd $= 33{,}000$ mmfd $= C_L = C_g$

The DC flows through both condensers; thus both condensers are given the same capacitance.

<u>3.3.) Calculating the DC voltage under load.</u>

In one valve array, 20 spark gaps of 1 mm each are connected in series at the instant of ignition, so that the ignition voltage of the mechanical rectifier is about 70 kV_{max}.

The magnitude of the load angle or contact angle is determined not only by the diameter of the balls, but also by the length of the arc between the balls. Figure 3 shows arc characteristics , with various arc lengths as parameter. It is seen that the arc becomes unstable even at short lengths, with the current of 0.5 A which would be used in practice. If the deionization, caused by the rapid movement of the ~~rolling~~ rotating balls, is also considered, it cannot be expected that the length of the arc will be greater than 1 cm. The arc length of 1 cm corresponds to a path of 3 cm of the rolling ball, at a ball diameter of 50 mm. Assuming that the path of the ball is 29 cm in diameter, the contact angle is calculated as:

SECRET

$(29\pi)/2 = 45.5$ cm $= 360^\circ$ el.

3 cm $= (360 \times 3)/45.5 = \underline{24^\circ}$ el. $= \underline{1.33 \times 10^{-3}\ s}$.

The test transformer has a stray inductance of

$e_s = 5.1\%$

$\omega L = [(e_s U^2)/N] \times 10^{-2} = [(5.1 \times 500^2)/0.25] \times 10^{-2} = 51{,}000$ ohms

$L = 51{,}000/314 = 162$ Henrys.

In order to avoid oscillations and overvoltage, the load circuit must be damped aperiodically.

$$R = 2\sqrt{L/C} = \sqrt{162/(33 \times 10^{-9})} = 140{,}000 \text{ ohms}$$

The charge of the condenser is calculated for the highest possible condenser voltage. The following conditions must apply in order to cause ignition in the rectifier:

$$U_{T_{max}} - U_{C_g} \geq U_Z = 70\ kV_{max}$$

By means of a retary regulator, the ignition point is set in such a way that the center of the contact angle and the peak of the transformer voltage will coincide. The transformer voltage will then change only little within the range of the contact angle. An approximate calculation can be carried out on the assumption that the condenser is being charged by a constant DC voltage through an ohmic resistance and a choke. Figure 4 shows the charging of a condenser through choke and resistance in a circuit with preponderant capacitance (Wallot 1944). The charging current increases with the time constant $\tau_1 = L/R$. The maximum of the current curve lies at the point where the voltage curve turns. The time constant $\tau_2 = RC$ determines the decrease in charging current and the increase in condenser voltage. The peak value of the current, calculated from voltage and resistance, is not reached, because the condenser voltage has increased in the meantime. An exact calculation, using differential equations or pointwise differentiation is a very time-consuming process. The curve of current and voltage is thus constructed by means of the time constant. We can thus assume that 80 % of the theoretical peak value of the current is reached.

The charging process is shown in Figure 5. At first, only the charge of the DC condenser by the transformer voltage will be considered.

Time constants:

$\tau_1 = L/R = 162/140{,}000 = 1.15$ ms $= (360^\circ \times 0.00115)/0.02 = 20^\circ$ el.

SECRET

$\tau_2 = R\,C = 140{,}000 \times 33 \times 10^{-9} = 4.6$ ms $= (360 \times 0.0046)/0.02 = 83^\circ$el.

Peak value of ~~x~~ charging current:

$J_L = 70{,}000$ V/ $140{,}000 = 0.5$ A

$J_L = 0.8 \times i_L = 0.4$ A

τ_1 must be drawn in for the full charging current $J = 0.5$ A and τ_2 for the driving voltage of 70 kV (Figure 5).

The charging current encloses an area of $F = 108$ mm^2.

The scales are as follows:

Abscissa: 12 cm = 360° el = 0.02 sec

1 mm = 1.666×10^{-4} sec

Ordinate : 1 mm = 0.02 A

Charge supplied to condenser:

$Q = 108$ mm^2 $\times$ 0.02 A/mm $\times$ 1.666×10^{-4} s/mm $= 3.6 \times 10^{-4}$ As.

The voltage of the condenser is thereby increased by

$$U_{CL} = Q/C = \frac{3.6 \times 10^{-4}}{0.033 \times 10^{-6}} = 1.09 \times 10^4 = 10{,}900 \text{ V}$$

The DC voltage always fluctuates between $U_{min} = 174$ kV and $U_{max} = 185$ kV with a DC delivery of

$Q = 3.6 \times 10^{-4}$ As per period or

$J_g = Q/t = 3.6 \times 10^{-4}/0.02 = 18$ mA

The DC is very low. Actually, it is probably still lower than that. In charging with AC voltage, the phase displacement has an effect, so that the current maximum will occur later than as calculated on the basis of DC voltage.

It must also be considered that the transformer voltage will be added to the ~~charge of conden~~ voltage on the charge condenser when the DC condenser is being charged. Since the charging process for both condensers is the same, the voltage of the DC condenser will increase to twice that of the charge condenser. Two voltage scales are shown in Figure 5 for this purpose. The DC voltage will thus be 360 kV with 18 mA DC load.

If the DC load is less than 18 mA, the voltage will remain the same. The ripple frequency, however, will change. After charging, under low load, the condenser voltage does not decrease ~~sufficiently~~ down to the ignition voltage until the next half-wave in equal phase ~~to reach the~~ is reached. ~~The~~ Ignition takes place only at a later period.

If the DC load increases above 18 mA, the charge lags behind the draining of power.

The DC voltage decreases until DC and charge are at equilibrium. The charge can be calculated for various minimum condenser voltages.

The transformer voltage is assumed to be constant and will remain at $U_T = 244$ kV at the instant of ignition. From Figure 5 it can be deduced that the charge can be calculated as a triangle

$$Q = \frac{1.1 \times \hat{J}' \times \alpha}{2} = \frac{1.1 \times \hat{J}' \times 1.33 \times 10^{-3}}{2} \text{ As}$$

The calculation is shown in the table below. The results are shown in Figure 6. Up to the critical load of 18 mA, the DC voltage remains constant.

At higher loads, the DC voltage decreases ~~so strongly~~ to such an extent that transformer control cannot compensate for it. This DC device ~~will~~ is thus suitable only for loads below 18 mA. Because of its low output, 6.5 kW, it cannot be used for corona measurements.

Villard Circuit with a Transformer:

	$U_{C_{gmin}}$	$i_L = (U_T - U_{Cg})/R$	$J_L = J_L \times 0.8$	$Q = \frac{1.1 \times \hat{J}_L \times \alpha}{2}$	$J_g = Q/0.02$
	kV	A	A	As	mA
1.	174	0.5	0.4	0.365×10^{-3}	18.2
2.	140	0.744	0.595	0.543×10^{-3}	27.1
3.	110	0.957	0.765	0.7×10^{-3}	35.0
4.	80	1.17	0.935	0.855×10^{-3}	42.7
5.	50	1.39	1.11	1.02×10^{-3}	51.0

	$U_{CL} = Q/C$	$U_{C_{gav.}} = U_{C_{gmin}} + \frac{1}{2}U_{CL}$	$U_g = 2U_{C_{gav.}}$	$N_g = J_g U_g$
	V	kV	kV	W
1.	11,000	179.5	359	6,530
2.	16,500	148.25	296	8,000
3.	21,200	120.6	241	8,430
4.	26,000	93.0	186	7,950
5.	31,000	65.5	131	6,690

4. The Villard Circuit with Ball Rectifier and with three Parallel Transformers

Since there are three test transformers available, ~~it is~~ an obvious ~~to try~~ way to increase the DC output without changing the design of the rectifier would be merely ~~to~~ connect~~ing~~ the transformers in parallel.

This circuit has the following advantages over a circuit using only one transformer:

1. Inductance and charging resistance are reduced to one-third
2. The charging current attains three times the value of the peak current
3. The higher charging current allows lengthening of the arc and thus makes possible a greater contact angle.

The disadvantage of this circuit lies in the danger of burning out ~~of~~ the contacts due to the high charging current.

Time constants: $\tau_1 = \frac{L/3}{R/3} = L/3 = 1.15 \text{ ms} = 20^\circ$ el.

$\tau_2 = R\,C = 1/3 \times 140{,}000 \times 33 \times 10^{-9} = 1.54 \text{ ms} = (360 \times 0.00154)/0.02 = 28^\circ$ el.

Contact angle: By means of Figure 2, the length of the arc is estimated at 2 cm. The ~~running~~ rotating ball covers a path of 48 mm.

$\alpha = (360 \times 4.8 \text{ cm}) / 45.5 \text{ cm} = 38^\circ \text{ el} = 12 \text{ mm}$

$\alpha = (0.02 \times 38)/360 = 2.11 \times 10^{-3}$ s

The charge is computed, as above, for the maximum DC at the same transformer voltage.

Ignition voltage: $U_Z = 70$ kV

Transformer voltage at instant of ignition: $U_{TZ} = 238$ kV

The charging voltage is no longer constant, since the contact angle has been increased. Therefore, the calculation is not made on the basis of the voltage at the instant of ignition, but rather on the basis of the average taken from the charging voltage at the instant of ignition and the peak point of the transformer voltage, thus:

$$U_L = \tfrac{1}{2}\,(U_{TZ} - U_{C_{gmin}}) + (U_T - U_{C_{gmin}})$$

Peak value of the charging current: $J_L = U_L / R$

$R = 140{,}000 / 3 = 46{,}660$ ohm.

The charging process is shown in Figure 6. Since the time constants τ_2 have decreased considerably, the charging current drops within the range of the contact angle. A further increase of the charging angle thus would not increase the charge to any marked degree. The area enclosed by the charging current in Figure 7 is approximately of the same size as the triangle formed by the charging angle as base line and the theoretical peak value of the charging current as height. The charge is thus computed as:

$$Q = (J_L \alpha)/2.$$

The charging current calculated in the table below is plotted in Figure 7 for the maximum DC. The ~~course~~ curve of ~~the~~ DC voltage under load is shown in Figure 8.

Up to a load of 85 mA, the DC voltage remains constant. If the load is increased by 40% to 120 mA, the DC voltage drops 40 kV or 10%. This voltage drop can be compensated for by means of the transformer control. Under a 140 mA load, the reduced charging current reaches the peak value of 2.1 A, or 0.7 A per transformer. Since the transformers are designed for 0.5 A_{eff}, the device can be loaded with a DC of 140 mA.

It remains now to be investigated, whether or not the high charging current will cause burning out of the contacts. Another disadvantage of this circuit lies in the fact that three parallel transformers will permit the setting up only of a single-phase DC measuring apparatus. The high charge by three transformers causes a strong ripple, amounting to 52 kV under critical load. Calculated on the basis of effective values, the DC voltage ripple ~~of the DC~~ will be:

$$(52 \times 100)/388 = 13.4\%$$

If the Villard circuit were to be used, it would have to be determined whether or not a sufficient DC output can be attained using one transformer and a contact angle which has been increased by redesigning.

Villard Circuit with Three Transformers

	$U_{C_{gmin}}$	$U_L = \frac{1}{2}(U_{TZ} - U_{C_{gmin}}) + (U_T - U_{C_{gmin}})$	$J_L = U_L/R$	$J'_L = 0.8\, J_L$
	kV	kV	A	A
1.	168	76	1.63	1.3
2.	150	94	2.01	1.61
3.	135	109	2.34	1.87
4.	120	124	2.66	2.12
5x				

	$Q = \frac{1}{2}(J_L \alpha)$	$J_g = Q/0.02$	$U_{C_L} = Q/L$	$U_{C_{g\,av.}} = U_{C_{g\,min}} + \frac{1}{2}U_{CL}$	$U_g = 2U_{C_{g\,av.}}$	$N_g = U_g J_g$
	As	mA	V	kV	kV	W
1.	1.72×10^{-3}	86	52,000	194	388	33,400
2.	2.12×10^{-3}	106	64,000	182	364	38,600
3.	2.47×10^{-3}	123.5	75,000	172.5	345	42,600
4.	2.8×10^{-3}	140	85,000	162.5	325	45,500

5.) ~~4.~~ The Greinacher Circuit with Grounding on one Side, with Increased Contact Angle

The Greinacher circuit (fig. 9), with grounding on one side, also doubles the voltage. However, the center of the condensers can also be grounded. Then the circuit consists of two half-wave circuits supplied by one transformer. A positive and a negative line with a peak voltage of $\pm$ 700 kV (500·√2) against ground can thus be ~~laid out~~ obtained from one transformer. However, in this case, the mechanical rectifier would have to be set up at an insulated location and the synchronous motor would have to be supplied through an insulated converter for the full DC voltage against ground.

If the center terminal of the condensers is grounded, each of the two DC voltages will have a single-phase ripple. If ~~the outsides~~ one of the end terminals of the condensers ~~are ground~~ is grounded, the DC voltage will have a two-phase ripple, and the rectifier can be grounded. The amplitude of the superimposed AC voltages will also decrease, because ~~after~~ supplementary charging of ~~a~~ the condenser takes place during each half-wave. It thus seems more practicable to set up two devices with two transformers and to ground them on one side.

We shall investigate a device with unsymmetrical grounding on one side by mathematical means.

Like in the Villard circuit, the no-load peak value of the DC voltage is:

$$U_g = 2\sqrt{2}\, U_{T\,eff} = 500 \text{ kV}$$

$$U_T = 500/(2\sqrt{2}) = 177 \text{ kV}_{eff} = 250 \text{ kV}_{max}$$

5.1. Dimensioning of the condensers

At half the DC voltage, each condenser must supply the full DC. Each condenser is charged once per period.

The capacitance of ~~a partial~~ each component condenser for 250 kV must therefore be the same as for the DC condenser of the Villard circuit.

$$C_g = 2C = 2x\ 33 \times 10^{-9} \text{ farad.}$$
$$U_g/2 = U_C = 250 \text{ kV.}$$

5.2. Calculation of the charge.

When undamped, the resonance frequency of the circuit is

$W_o = 1/\sqrt{LC} = 1/(162 \times 3.3 \times 10^{-8}) = 435$

$f_o = W_o/(2\pi) = 69$ cps.

The damping resistance is calculated for the aperiodic limiting case:

$R_d = 2\sqrt{L/C} = 2\sqrt{162/(3.3x10^{-8})} = 140{,}000$ ohms.

Ratio between frequency of AC circuit and of undamped circuit:

$\delta = W_\sim/W_o = 314/435 = 50/69 = 0.722$

$\delta^2 = 0.522$

The instantaneous value of the AC is given by the equation:

$$i = \sqrt{2}\, \frac{U_{\sim E}}{W_{\sim L}} \times \frac{\delta^2}{1+\delta^2} \left\{ \sin (w_\sim t + \varphi) - [A + \omega_\sim(t - t_z)\ B] \mathcal{E} - w_o(t - t_z) \right\}$$

Calculation of the constants:

φ = arc tan $\frac{1}{2}(1/\delta - \delta)$ = arc tan $\frac{1}{2}(1/0.722 - 0.722)$ = arc tan 0.3315 = arc tan 18°20'

= 0.32

The ignition point is chosen as:

$t_z = 60° = (0.02 \times 60)/360 = 0.00333$ s

$A = \sin(w_\sim t_z + \varphi) = \sin(314 \times 0.00333 + 0.32) = \sin 78.5° = 0.98$

$p = U_k/\hat{U}_\sim = 70{,}000/250{,}000 = 0.28$

$P = \sin(w_\sim t_z) - p = \sin 1.05 - 0.28 = 0.587$

$B = 1/\delta^2 \times us(w_\sim t_z + \varphi) + P\frac{1+\delta^2}{\delta^2} - 1/\delta \times \sin(w_\sim t_z + \varphi) =$

$(1/0.522) \times 0.199 + 0.587\ [(1+0.522)/0.522](1/0.722)\ 0.98 = 0.736$

$wL = 314 \times 162 = 51{,}000$ ohms.

$i_\sim = \sqrt{2}\ (U_{\sim E}/w_{\sim L})\ [\delta^2/(1+\delta^2)] \left\{ \sin(w_\sim t + \varphi) - [A + w_\sim(t - t_z)B\ \mathcal{E} - (w_o(t - t_z)\ A] \right\}$

$=(250{,}000/51{,}000)\ (0.522/1.522) \{ \sin(314\ t + 0.321 - 0.98 + 314(t-0.00333)0.736 \times$

$\mathcal{E} - 435(t-0.00333) \}$

$i_\sim =(1.68 \sin 314\ t + 0.32) - 0.98 + 231(t-0.00333) - 435(t-0.00333)$

(Note: These formulae may contain errors or omissions)

The charging current was calculated according to the above formula. The results are shown in the table below. For purposes of abbreviation, the following terms of the formula have been replaced by letter symbols:

$(314\ t + 0.32) = a$

$(t - 0.00333) = b$

$0.98 + 231\ b \times \varepsilon^{-435\ b} = A$

Using those abbreviations, the formula for the charging current is

$i = 1.68\ (\sin a - A)$

Time t in degrees	72	90	108	126	144
time t in seconds	0.004	0.005	0.006	0.007	0.008
314 t	1.258	1.570	1.888	2.200	2.515
314 t + 0.32 = a	1.578	1.890	2.208	2.520	2.835
314 t + 0.32 = a	90.5	108.2	126.5	144.3	162.3
sin a	1.0	0.9500	0.8039	0.5835	0.3040
~~XX~~ t-0.00333 = b	0.00067	0.00167	0.00267	0.00367	0.00467
231b	0.155	0.386	0.6165	0.8485	1.08
0.98+231 b	1.135	1.366	1.5965	1.8285	2.06
435 b	0.2915	0.727	1.161	1.596	2.030
435 b log [?]	0.1265	0.3155	0.5045	0.6945	0.8815
435b	1.338	2.065	3.197	4.925	7.60
- 435 b	0.748	0.4845	0.313	0.203	0.1316
$0.98 + 231\ b^{-435\ b} = A$	0.85	0.661	0.5	0.371	0.271
sin a - A	0.15	0.289	0.304	0.2125	0.033
i = 1.68(sin a - A)	0.252	0.486	0.511	0;357	0.0555

Time ~~Sec~~ Degrees	~~Degrees~~ Sec	10^{-3}	Area(158) mm^2	Area, total mm^2	Q 10^{-6} As
60	0	0	0	0	0
75	15	0.834	150	150	125
90	30	1.668	380	530	443
105	45	2.5	514	1044	871
120	60	3.334	489	1533	1280
135	75	4.169	336	1869	1560

U_{CL} V	$U_{C_{min}} + U_{CL}$ V
0	146000
3785	149785
13400	159400
26400	172400
38800	184800
47250	193250

Figure 11 shows that the contact angle is favorable between 60^0 and $135°$. At ignition before $60°$, the minimum condenser voltage decreases too much with respect to the peak value of the transformer voltage, due to the high ignition voltage, so that the blocking voltage is increased. At an extinction point later than $135°$ there is danger of arcback. If the DC load is below the critical value, the ignition voltage is not reached. Toward the end of the contact angle, however, the condenser voltage may be higher by the amount of the ignition voltage than the transformer voltage, if the contact angle is too large. In that case, the condenser will discharge through the transformer.

For purposes of comparison with the simplified method used above, the charging current is to be calculated also for a given DC by means of the time constants.

$\tau_1 = L/R = 1.15$ ms $= 20°$ el

$\tau_2 = RC = 4.6$ ms $= 83°$ el

In the Villard circuit with one transformer, the contact angle was only $\alpha = 24°$. In this region, the voltage hardly changes, so that the figure for the ignition voltage can be assumed to be that for the charging voltage.

In the Villard circuit with three transformers, the charging angle was $\alpha = 38°$ el, so that the instantaneous values of the voltage show much more marked differences. The calculation therefore employs the average value taken from the voltage at the instant of ignition and at the peak point. ~~For purposes of control~~ As a check, this method is also employed here.

$U_L = (70 + 104)/2 = 87$ kV

$J_L = 87/140 = 0.62$ A

$J_{L'} = 0.8\, J_L = 0.5$ A

The actual value is 0.52 A. The accuracy is sufficient ~~for a principal~~ for general purposes. ~~consideration.~~

In the Villard circuit with three transformers, the charge was computed by means of the triangle as:

$$Q = \tfrac{1}{2}(\hat{J}_L \alpha)$$

Because of the large contact angle, the value obtained here by this method is too low:

$$Q = \tfrac{1}{2}(\hat{J}_L \alpha) = (0.62 \times 4.165 \times 10^{-3})/2 = 1.29 \times 10^{-3} \text{ As}$$

The calculation is more exact if the reduced charging current $J_{L'}$ of 87% is used as the height and the sum of the time constants as the base.

$$Q = \frac{J_L \times (\tau_1 + \tau_2)}{2} = \frac{0.54(1.15+4.6) \times 10^{-3}}{2}$$

$$Q = 1.55 \times 10^{-3} \text{ As}$$

$$U_L = \frac{Q}{C} = \frac{1.55 \times 10^{-3}}{3.3 \times 10^{-8}} = 47{,}000 \text{ V.}$$

Thus, the values for charge and voltage are the same as those obtained by the exact calculation method. The voltage curve is calculated by the simplified method. The values of the table below are shown in Figure 12.

The Greinacher circuit can be loaded up to 75 mA without voltage drop. Above that load, the voltage drops at a rate of 1.6 kV per mA. The circuit can be loaded up to 100 mA. At 75 mA, the ripple is of the two-phase kind, i.e. f = 100 cps with a voltage fluctuation of 47 kV for one condenser.

This does not take into account the fact that discharge will cause the voltage on both condensers to drop ~~during charging. By~~ while one condenser is being charged. With a contact angle of 75° the voltage will drop by $(47 \times 75°)/360° = 9.8$ kV. The voltage sum at 75° thus drops by 2 x 9.8 or 19.6 kV.

This gives an approximate effective value of $19.6/(2\sqrt{2}) = 6.93$ or approx. 7 kV.

Calculating on the basis of 400 kV, we obtain a ripple of 1.75%. Thus, smoothing of the DC can be dispensed with.

Greinacher Circuit

	$U_{C_{g\,min}}$	$U_L = \frac{1}{2}(U_Z - U_{C_{min}}) + (U_T - U_{C_{min}})$	$i_L = U_L/R$	$i'_L = 0.87 \times i_L$
	kV	kV	A	A
1.	146	$\frac{1}{2}(70 + 104) = 87$	0.62	0.54
2.	130	$\frac{1}{2}(86 + 120) = 103$	0.736	0.64
3.	115	$\frac{1}{2}(101 + 135) = 118$	0.842	0.732
4.	100	$\frac{1}{2}(116 + 150) = 133$	0.95	0.826

	$Q = \frac{1}{2}\, i'_L\, (J_1 + J_2)$	$i_g = Q/0.02$	$U_{CL} = Q/C$	$U_{C_{g\,av}} = U_{C_{g\,min}} + \frac{1}{2}U_{CL}$	$U_g = 2\, U_{C_{g\,av}}$
	As	mA	kV	kV	kV
1.	1.552×10^{-3}	77.6	47.0	169.5	339
2.	1.84×10^{-3}	92	55.7	158	316
3.	2.102×10^{-3}	105.1	63.7	147	294
4.	2.375×10^{-3}	118.75	71.9	136	272

	$N_g = i_g\, U_g$
	kW
1.	26.3
2.	29.1
3.	30.9
4.	32.3

6. The Three-Phase Bridge Circuit with Three Ball Rectifiers

Like the Villard circuit and the Greinacher circuit, the bridge circuit (Fig. 13) also doubles the transformer voltage. Each phase carries current for 120° el. in each half-period, so that the transformers are best utilized in this circuit. In comparison with the other circuits, this one is capable of carrying the highest load. The ripple of the DC is six-phase, so that smoothing is greatly facilitated. However, the amplitudes of the harmonics are great, because the rectifier has a high ignition voltage which is fully effective without the inclusion of a charging condenser in the circuit. The DC must therefore be smoothed under any conditions.

A disadvantage is fact that the circuit requires three transformers. Therefore only a single-polarity DC can be produced. One DC ~~pole~~ terminal must be grounded. If the grounding is symmetrical with respect to the DC voltage, i.e. if the star point of the transformer is grounded, the rectifiers must not be grounded. The synchronous motors would have to be supplied through three separate ~~insulating~~ isolating converters which would have to be insulated against ground for the peak value of the DC voltage.

The large contact angle of 120° el. for the mechanical rectifiers is an unfavorable design feature.

The curves of the potentials of the switching points are shown in Figure 13. As with all circuits, they are based on a transformer voltage of $U_T = 250\ kV_{max}$. The ignition voltage of 70 kV increases the ripple which shows a voltage difference of 90 kV. Therefore, smoothing is required. The DC voltage has a mean value of $U_{g_m} = 410$ kV. The secondary phase current of the transformer is calculated as

$$J_{II} = 0.816\ J_g.$$

The permissible DC is thus:

$$J_g = J_{II} / 0.816 = 0.5/0.816 = 0.612\ A$$

In the bridge circuit, the rated output [Typenleistung] of the transformer is only $N_u = 1.05\ N_g$. Accordingly, the DC load can be increased to 250/1.05 = 238 kW. The blocking voltage of the valve arrays, at a DC voltage of 410 kV, must be

$$U_{sp} = 2.48\ U_T = 433\ kV.$$

6.1. Smoothing of the Voltage in Three-phase Bridge Circuit

~~Basic~~ Fundamental frequency of the AC voltage superimposed on the DC voltage, according to Figure 13 : f = 300 cps

Peak value of the DC voltage: $U_{max} = 430$ kV

Lowest instantaneous value of the DC voltage: $U_{min} = 340$ kV

Estimated effective value of the fundamental wave: $U = (430 - 340) / 2\sqrt{2} = 31.8$ kV

or, roughly, $U = 30\ kV_{eff}$, 300 cps.

In order to avoid setting up an oscillating circuit made up of choke and condenser, the voltage smoothing is to be attempted by means of an ohmic resistance and a condenser.

Figure ~~14~~ 15 shows the equivalent circuit diagram. The permissible voltage drop on the resistance, at a DC load of 50 mA, is

U_R = 2% = 8 kV

Magnitude of the smoothing resistance:

$R = U_{rg}/J_g = 8000/0.05 = 160,000$ ohms

The ~~xxxx~~ superimposed fundamental wave, ~~xxxxxxxxxxxxxxxx~~, is to be reduced to an effective value of 2% of the DC voltage:

$U_w = 8000\ V_{eff}$

AC voltage on the smoothing resistance:

$U_R = \sqrt{30^2-8^2} = 29,000$ V.

AC in the smoothing resistance:

$J_w = 29,000\ V/\ 160,000 = 0.181$ A

Capacitance of the smoothing condenser:

$C = J_w / (\omega U_w) = 0.181 / (2\pi \times 300 \times 800) = 12,000$ mmfd.

Power in ~~Output on~~ the smoothing resistance:

$N_g = J_g^2 \times R = 0.05^2 \times 160,000 = 400$ W

$N_w = J_w^2 \times R = 0.181^2 \times 160,000 = 5250$ W

$N_w + g = 5650$ W.

The power dissipated in ~~work to be performed at~~ the resistance is too high for air cooling. The superimposed AC, of 0.181 A, with a rated transformer current of 0.5A, is also quite high. If the smoothing resistance is increased, the voltage drop due to the DC becomes undesirably large. It thus seems more practicable to effect the smoothing by means of a choke and a condenser connected in series.

As above, the DC voltage is to be smoothed to a 2% ripple. The superimposed AC should not be greater than $J_w = 0.05$A, because of the transformer load.

Capacitance of the smoothing condenser:

$C = J_w/(U_w \omega_\sim) = 0.05/(8000 \times 2\pi \times 300) = 3320$ mmfd.

Since the condenser can be given larger dimensions at little extra cost, its capacitance was chosen as 5,000 mmfd.

Voltage on the condenser:

$U_C = J_w/\omega C = 0.05/(2\pi\ 300 \times 5 \times 10^{-9}) = 5,300$ V.

Voltage on the choke:

$U_p = U_\sim - U_C = 30,000 - 5,300 = 24,700$ V.

Inductance of the choke:

$L = U_D/(J_w \omega) = 24,700/(0.05 \times 2\pi \times 300) = 262$ henrys.

6.2. ~~Ohmic~~ Damping resistance

In the process of swithhing on of the apparatus, i.e. during ignition of the rectifier, the ~~stray~~ leakage inductances of two transformers and the smoothing choke are in series.

$L = 162 + 162 + 262$

$L = 586$ ~~cps.~~ henrys.

Resistance for aperiodic damping :

$R = 2\sqrt{L/C} = 2\sqrt{586/(5x10^{-9})} = 684,000$ ohms, or, approx. 700,000 ohms.

A damping resistance of $R_d = R/2 = 350,000$ ohms is required for each transformer.

Voltagg drop due to damping resistances:

$U_R = J_g \times 2 \times R_d$

J_g mA	U_R V
20	14,000
50	35,000
100	70,000

The damping resistance becomes four times as great as the smoothing resistance. It would thus be more practicable, after all, to increase the smoothing resistance and to leave out the damping resistances and the choke.

The new smoothing resistance was chosen ~~at~~ as: R = 300,000 ohms.

AC voltage on the smoothing resistance, as above: $U_R = 29,000$ V.

AC in the smoothing resistance: $U_w = 29,000/300,000 = 0.0966$ A.

Capacitance of the smoothing condenser: $C = J_w / (\omega U_w) = 0.0966/(2\pi \times 300 \times 8000)$

$= 6410$ mmfd.

Capacitance chosen: 10,000 mmfd.

DC voltage drop and ~~output at~~ power in the resistance:

J (ma)	J^2 R (W)	JR (V)
10	30	3,000
30	270	9,000
50	750	15,000
70	1470	21,000

7. The Single-Phase Bridge Circuit with two Ball Rectifiers and Increased Contact Angle

The principle of the single-phase bridge circuit is shown in Figure 16. The potential curves are shown in Figure 17. The DC condenser is charged by the full transformer voltage during each half period. The ripple of the DC is therefore two-phase. The transformer utilization factor is high, so that a high DC load is possible.

The disadvantage of this circuit lies in the necessity of setting up two separate rectifiers for one set. These rectifiers must run synchronously, displaced in phase by 180°. The transformer cannot be grounded, as in the Greinacher circuit. The two lines increase the dimensions of the apparatus.

The theoretical peak value of the DC voltage is $U_g = U_{T_{eff}} \sqrt{2}$. The blocking voltage, however, is

$$U_{sp} = U_{T_{eff}} \times 2 \times \sqrt{2}.$$

This is twice as high as the DC voltage generated. The charging process resembles that of the Greinacher circuit. The contact angle thus can also be set at 75° el.

The calculation is the same as in the case of the Greinacher circuit.

7.1. Dimensioning of the DC condenser.

Maximum DC: $J_g = 0.05$ A

Average DC voltage: $U_g = 400$ kV

As before, the permissible voltage fluctuation is 30 kV.

Since this charging process covers 75°, the discharge of the condenser takes place in $\beta = 180° - 75° = 105°$ el. or

$\beta = (0.01 \times 105°)/180° = 0.00584$ seconds.

Discharge:

$Q_e = 0.05 \text{ A} \times 0.00584 \text{ seconds} = 2.9 \times 10^{-4}$ As.

$U_{max} = 500$ kV

$U_{min} = 470$ kV

1.) $Q = C\, U_{max}$

2.) $Q' = C\, U_{min}$

3.) $Q_o = Q - Q' = 2.9 \times 10^{-4}$ As.

1,2.) $Q' = Q \times 470/500$ (cf. above, Villard circuit)

3.) $Q - Q \times 470/500 = 2.9 \times 10^{-4}$ As

$30/500\, Q = 2.9 \times 10$

$Q = 0.00484$ Coulomb

1.) $C = Q/U_{max} = 0.00484/\ 500{,}000$

$C = 0.00967\ \cancel{\mu\mu f}$ mmfd $= 0.01\ \cancel{\mu\mu f}$ mmfd $= 10{,}000$ mmfd .

7.2. Calculation of the load characteristic

Contact angle, like in the Greinacher circuit, $= 75^\circ$ el. $= 4.165 \times 10^{-3}$ sec.

Damping resistance:

$R = 2\sqrt{L/C} = 2\sqrt{162/10^{-8}} = 250{,}000$

Because of the small condenser, the damping resistance becomes very high. Therefore, the peak value of the charging current ~~become~~ would be lower than it would have been on the basis ~~to in consideration~~ of the transformer output. The condenser should therefore ~~be~~ have dimensioned ~~to~~ twice the calculated capacitance.

$C = 20{,}000$ mmfd.

New damping resistance:

$R = 2\sqrt{L/C} = 2\sqrt{162/(2 \times 10^{-8})} = 180{,}000$ ohms

A value twice that used for the Villard and Greinacher circuits must be used for the transformer voltage.

$U_T = 500$ kV

$U_{Teff} = 354$ kV

Time constants: $\tau_1 = L/R = 162/180{,}000 = 0.9$ ms $= 16^\circ$ el.

$\tau_2 = RC = 180{,}000 \times 2 \times 10^{-8} = 3.6$ ms $= 64^\circ$ el.

Charging voltage: The calculations are carried out as in the case of the Greinacher circuit.

$U_L = \frac{1}{2}[(U_Z - U_{Cmin}) + (U_T - U_{C\,min})]$

$U_Z = U_T \sin wt_z = 500 \times 0.866 = 434$ kV

$U_Z - U_{Cmin} = 70$ kV

$U_{Cmin} = 434 - 70 = 364$ kV

$U_L = \frac{1}{2}(70 + 136) = 103$ kV

Charge:

The calculation of the condenser charge is carried out according to the method used for the Greinacher circuit.

$Q = [i'_L(\tau_1 + \tau_2)]/2$

$\hat{i}_L = U_L/R = 103/180 = 0.57$ A

$\hat{i}'_L = 0.8\ \hat{i}_L = 0.46$ A

$Q = \frac{1}{2} [0.46 \ (0.9 + 3.6) \ 10^{-3}] = 1.035 \times 10^{-3}$ As

With the larger charging angle of 75°, the discharge of the condenser due to the corona current during the charging time cannot be neglected. For the sake of simplicity, we shall at first carry out the calculation as though there were no load during the charging time. The DC is calculated on the basis of full load. ~~In determining the DC, the full load is taken into consideration.~~ The correct condenser charge can be determined only by that method.

$i_g = Q/t = (1.035 \times 10^{-3})/0.01 = 103.5$ mA

During the contact time the discharge is:

$Q_\alpha = i_g \alpha = 103.5 \times 10^{-3} \times 4.165 \times 10^{-3} = 0.432$ As

The condenser charge is lower by Q_α than the charge Q supplied by the transformer.

$Q_C = Q - Q_\alpha = (1.035 - 0.432) \ 10^{-3}$ As $= 0.603 \times 10^{-3}$ As

The condenser voltage is increased by

$U_C = Q_C/C = (0.603 \times 10^{-3})/(2 \times 10^{-8}) = 30150$ V

$U_C = 30{,}000$ V

The calculation can be simplified. The discharge by the DC during the time of contact is:

$Q_\alpha = Q \times \alpha/180$

Actual charge of the condenser:

$Q_C = Q - Q_\alpha = Q - Q \times \alpha/180$

$Q_C = Q \ (1 - \alpha/180)$

$Q_C = Q \times 0.584$

Voltage increase of the condenser:

$U_{CL} = (Q \times 0.584) / C = (1.035 \times 10^{-3} \times 0.584) / (2 \times 10^{-8}) = 30{,}000$ V

SECRET

Singe-Phase Bridge Circuit

$U_{C_{gmin}}$	$U_L = \frac{1}{2}[(U_Z - U_{C_{gmin}}) + (U_T - U_{C_{gmin}})] = \frac{1}{2}[(434 - U_{C_{min}}) + (500 - U_{C_{min}})]$	$i_L = U_L/R$
kV	kV	A
1. 364	103	0.572
2. 350	117	0.67
3. 335	132	0.757
4. 320	147	0.841

	$i_L' = 0.8\, i_L$	$Q = \frac{1}{2} i_L (T_1 + T_2) = 2.25 \times 10^{-3}\, i_L$	$i_g = Q/T$	$Q_C = Q \times 0.584$	$U_{CL} = Q_C/C$
	A	As	mA	As	V
1.	0.458	1.03×10^{-3}	103	0.6	30,000
2.	0.537	1.205×10^{-3}	120.5	0.704	35,200
3.	0.604	1.36×10^{-3}	136	0.794	39,700
4.	0.673	1.515×10^{-3}	151.5	0.884	44.200

	$U_{C_{gav.}} = U_{C_{min}} + \frac{1}{2} U_{CL}$	$N_g = i_g\, U_{C_{gav.}}$
	~~kV~~ Volts	kW
1.	379,000	39
2.	367,600	44.3
3.	354,850	48.3
4.	341,100	51.7

Figure 18 shows the transformer voltage and the DC voltage on the condenser at critical load, i.e. at maximum DC voltage and with the maximum DC which can be attained without a voltage drop.

Figure 19 shows the DC voltage as a function of the load. At above-critical load, the voltage drops at a rate of 0.8 kV per mA. The circuit can be loaded with more than 100 mA. Thus the bridge circuit is the most efficient of the circuits employing one transformer.

The advantage of the high load capacity of the circuit is canceled by the disadvantage of the necessity for a large amount of equipment. Two rectifiers must be used. Each valve array must have a blocking voltage rating of 1000 kV_{max}, as compared to 500 kV in the Greinacher and the Villard circuits.

8. Comparison of the Circuits Discussed Above

The table below gives a compilation ~~of~~ the circuits investigated ~~with the~~ (of the ~~most~~ important data, for)

The greatest DC is supplied by the three-phase bridge circuit. This circuit is the only one in which the ~~hum~~ ripple does not depend on the load. The three-phase bridge circuit, however, cannot be used for the corona measuring apparatus, because it can generate only a single-~~phase~~ polarity DC voltage against ground. For corona measurements, a ~~two-phase~~ double-polarity DC voltage with grounded center is more appropriate, since not all the (corona) charge carriers travel from the line to ground, but also from one line to the other.

The single-phase bridge circuit is also very efficient. However, this circuit also does not warrant consideration, since it requires two rectifiers with four valve arrays and a blocking voltage rating of 1000 kV per valve array. All other circuits require a blocking voltage rating of only 500 kV.

The Greinacher and the Villard circuits still remain to be considered. The ~~[illegible]~~ Greinacher circuit supplies a better DC voltage, because a DC voltage condenser is supplied with a ~~residual~~ supplementary charge [nachgeladen] ~~per~~ each half-period. The fundamental frequency of the superimposed AC voltage is twice as high and the amplitude only half as great as in the Villard circuit. No special smoothing of the DC voltage is required in the Greinacher circuit, since the effective value of the fundamental wave at 75 mA DC voltage is only 3.9% of the DC voltage. The Greinacher circuit is also the cheapest to build.

It is therefore suggested that two single-phase sets on the principle of the Greinacher circuit be built for corona measurements. Each set shall consist of the following components:

1 testing transformer, 500 kV (from the three-phase DC measuring set)

1 mechanical rectifier, blocking voltage 500 kV_{max} per valve array, contact angle 75° el.

1 damping resistor, 140 kilohm

2 condensers, 33,000 [illegible] each, 250 kV.

Comparison of the Circuits

	Villard circuit with 1 transformer	3 transformers
No. of transformers	1	3
Transformer peak voltage U_T, kV	250	250
DC ~~peak~~ voltage, U_g	$2\sqrt{2}\ U_{T_{eff}} = 500$	$2\sqrt{2}\ U_{T_{eff}} = 500$
DC voltage, mean value, U_g, kV	360	388
Amplitude of DC voltage ripple, kV	5.5	26
DC voltage, (ripple) based on 400 kV, %	1.4	6.5
superimposed AC voltage, kV_{eff}	3.9	18.4
superimposed AC voltage based on 400 kV, %	1	4.6
superimposed AC voltage, frequency	50	50
critical DC, J_{gk}, mA	18	86
maximum DC, $J_{g\,max}$, mA	18	140
above-critical voltage drop, kV/mA	7	1.2
No. of mechanical rectifiers	1	1
Rectifier blocking voltage, kV_{max}	500	500
Rectifier contact angle, °el.	24	38
No. of DC condensers	2	2
Condenser voltage, kV	250 and 500	250 and 500
Condenser capacitance, mmfd	2 x 33,000	2 x 33,000
No. of damping resistances	1	3
Ohmic value of resistances	140,000	3 x 140,000
Capacitance of smoothing condenser, mmfd	-	-
Ohmic value of smoothing ~~condenser~~ resistance	-	-

SECRET

Greinacher circuit	Bridge circuit single-phase	Bridge circuit three-phase
3	1	3
250	500	250
$2\sqrt{2}\ U_{T_{eff}} = 500$	$\sqrt{2}\ U_{T_{eff}} = 500$	$2\sqrt{3}\ U_{T_{eff}} = 433$
339	379	max 410
10	15	45
2.5	3.8	11
15.5	10.6	31.8
3.9	2.7	8
100	100	300
77	100	-
100	160	600
1.6	0.8	0.7
1	2	3
500	1000	500
75	75	120
2	1	-
2 x 250	500	-
2 x 33,000	20,000	-
1	1	-
140,000	180,000	-
-	-	1 x 10,000
-	-	300,000

SECRET

List of Illustrations

Leistung = output

Aufladung = charge

Gleichstrom = DC

Figure 9: Greinacher circuit. Circuit diagram.

Figure 10: Greinacher circuit. Potential curves.

Gleichspannung bei Erdung von...= DC voltage with ... grounded

Spannung = voltage

Figure 11: Greinacher circuit. Condenser charging.

Spannung = voltage

Strom = current

Berechneter Ladestrom = calculated charging current

Masstab = scale

Figure 12: Greinacher circuit. DC voltage as function of load.

Gleichspannung = DC voltage

Leistung = output

Aufladung = charge

Gleichstrom = DC

Figure 13: Three-phase bridge circuit. Circuit diagram.

Figure 14. Three-phase bridge circuit. Potential curves.

Gleichspannung = DC voltage

Spannung = voltage

Zündspannung = ignition voltage

Spannungen gegen den Sternpunkt = potentials against star point (= neutral)

Fig. 15. : Voltage smoothing in three-phase bridge circuit.

Figure 16: Single-phase bridge circuit. Circuit diagram.

Figure 17: Single-phase bridge circuit. Potential curves.

Spannung = voltage.

Figure 18: Single-phase bridge circuit. Condenser charging.

Spannung = voltage

Trafospannung = transformer voltage

Gleichspannung = DC voltage

Figure 19: Single-phase bridge circuit. DC voltage as function of load.

Gleichspannung = DC voltage

Leistung = output

Aufladung = charge

Gleichstrom = DC.

Handwritten pages: Errata. The text of the translation has been corrected accordingly.